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Performance Evaluation of 3-RRPaR Parallel Manipulator in Pick and place Operation

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Abstract

This study evaluates the performance of a 3-RRPaR parallel manipulator designed to perform pick-and-place operations. The manipulator consists of three actuators driven by stepper motors, which are controlled through a G-code interface using Universal G-Code Sende.. Motion commands are input via a computer, enabling the robot to follow predefined trajectories. During testing, the manipulator was programmed to move within a circular workspace with a radius of 100 mm on the X and Y axes. The actual movement reached only 98 mm, resulting in a positioning error of approximately 2 mm. The observed inaccuracies are primarily attributed to structural inconsistencies between the upper and lower frames, unequal lengths of the passive links, and the use of a non-permanent clutch mechanism. These findings highlight the importance of mechanical precision and structural symmetry in enhancing the accuracy of parallel manipulator systems.

Keywords: Parallel Manipulator, 3-RRPaR, Pick and place, Positioning Accuracy, Stepper Motor Control

1. Introduction

The human need for more modern and practical technology is increasing, one of which is automated control systems. Work that was previously done manually is being automated by implementing computers in control systems. The combination of computers and mechanical equipment will undoubtedly create a new dimension of interest for many. One such task that can be automated is moving materials or goods from one location to another.

Moving large quantities of materials can potentially lead to inconsistencies in requirements. Some moving tasks require a fast pace, such as packing biscuits or snacks into packaging boxes in the food industry. This task requires repeated moving processes over a specific distance. If done manually with a large number of human workers, people will become fatigued. When fatigue occurs, they lose concentration in moving the snacks, potentially leading to food spoilage.

The use of industrial robots is a key component in automation technology that can function like human workers in factories, but have the ability to work continuously without fatigue. One robot that is often used in industry is the manipulator robot. This is evidenced by the increase in industrial robot sales by 59%, namely 183,000 units in 2016 for the Asian region alone. An example of the use of manipulator robots is in the process of moving goods. In carrying out this task, the manipulator robot moves goods from one point to another. In carrying out this movement, a method is needed to make the robot move to the desired position. This need has led to a lot of research on the movement of manipulator robots. Richard P. Paul has succeeded in deriving kinematic equations for each manipulator determined from the position in Cartesian coordinates and the orientation of the end effector given from the coordinates of each joint on the manipulator.

Then, in 2012, Jin Huang created a simulation for joint movement on a manipulator using a more efficient and accurate inverse kinematics method, but it has not been applied to a real manipulator. In 2013, Yang Si found a solution to the inverse kinematics method on a 4 DOF (Degree of Freedom) manipulator robot. Based on this research, to solve the inverse kinematics problem depends on the kinematic structure of the manipulator. Thus, the procedure also comes from how long the manipulator structure changes. The derivation of the inverse kinematics method can be known after conducting a kinematics analysis on the manipulator robot. The kinematics model is obtained by describing the geometry of the robot. From the geometric image, the Denavit-Haternberg Parameter and its homogeneous transformation matrix can be found. After obtaining the results of the kinematics modeling of the manipulator robot, the inverse kinematics of the manipulator robot can be calculated. The inverse kinematics method is used to calculate the angles of each joint on the manipulator with the known end effector position.

A robot manipulator is a robot with an arm that provides robot movement to rotate, fold, and reach objects. This movement is called Degree of Freedom (DoF) or the number of axes on the robot. The manipulator consists of several segments (links) and joints. The manipulator has 2 parts, namely the base part and the additional part. The base part of the manipulator can be rigid (rigid bodies) attached to the floor of the work area (workspace). The additional part is an extension of the base part, also called the arm. The end part is attached to the effector (end-effector) which functions as a tool that will perform a job at the end of the robot. The manipulator is driven by an actuator or called a drive system. The actuator or drive system causes various movements of the manipulator [1]. The robot manipulator is assembled from a series of rigid bodies, links and joints that connect the links. Each joint position is determined by a single variable so that the number of joints is equal to the DoF value [2].

Robot manipulators are very useful in the Industry 4.0 era and are widely used in the industrial sector, especially in the manufacturing and packing sections of a factory. In addition to saving time, robots are used to produce products that are much better than using conventional machines or human hands [3].

Parallel to the development of teleoperators was the development of Computer Numerically Controlled (CNC) machine tools for accurate milling of low-volume, high-performance aircraft parts. The first robot, the “Unimate” in Figure 2.2, developed by George Devol in 1959, replaced the teleoperator’s master manipulator with the programmable capabilities of a CNC machine tool controller [4].

In the era of the fourth industrial revolution, mechatronics and robotics play an increasingly important role. Compared with serial robot manipulators, parallel robot manipulators have the advantages of higher accuracy, because the errors between pins are compensated for each other without having to accumulate on the same pin, lighter moving link mass, better stability. Although the disadvantages of parallel robots are that their working space is smaller and require more complex singularity analysis than serial robots, robot manipulators are often used for high-speed and high-precision tasks [5].

A single-arm manipulator robot has an arm that can be considered as a cantilever beam, where one end is clamped and the other end is free. The well-known theory in deriving a mathematical model for a beam is the Euler-Bernoulli Theory. Later Rayleigh improved the Euler-Bernoulli model by adding the effect of rotational inertia caused by the rotational motion of the cross-section during vibration of the beam [6].

An industrial robot consists of a robot manipulator, a power supply, and a controller. A robot manipulator consists of several connected joints. The wrist is used to direct the position of objects at the work site. A robot manipulator is created from a sequence of links and joint combinations. A link is a rigid member that connects joints. An axis is a moving component of a robot manipulator that causes relative motion between adjacent links. Mechanical joints are used to build a robot manipulator arm. Mechanical joints consist of five main types, namely two of linear joints and three rotary types. Two of the linear joints are relative motion between adjacent links or called non-rotational. While the three rotary types are relative motion that involves rotation between links [7].

A robot manipulator is a mechanical part that can be used to move, lift, and manipulate work objects. A robot manipulator is a type of robot arm with a load-carrying arm material. Robot manipulators can carry loads in moving locations, are made of thin materials, are lighter, more efficient in power consumption, only require small actuators, are easier to operate, and are cheaper in the manufacturing process. Currently, robots are widely used in the industrial world along with rapid technological developments and flexible production [8].

A parallel robot is a spatial mechanical structure consisting of a closed kinematic chain. Generally, a parallel manipulator has two platforms. One is attached to a fixed reference frame. The other can have arbitrary movements in its workspace. Three movable legs, made as a serial robot, connect the effector, attached to the movable platform, to the fixed platform. The robot elements are connected to each other by ball joints, revolute joints or prismatic joints [9].

A parallel manipulator robot is a closed-loop mechanism where the final end-effector is connected to two independent kinematic chain bases. A fully parallel manipulator is a closed-loop mechanism with the end-effector having degrees of freedom (DFR) connected to independent kinematic chain bases that have a maximum of two links driven by prismatic actuators [10].

A parallel manipulator is a type of robot that consists of a moving platform, a base and two or more limbs. The entire system forms a closed loop [11].

A serial robot is a robot whose kinematic structure is in the form of an open-loop chain consisting of several links connected in series by various types of joints, usually revolute and prismatic. One end of the robot is attached to the ground and the other end is free to move in space. The fixed link is called the base, and the free end where the gripper or mechanical hand is attached, the end effector of the serial manipulator robot [12].

The 3-RRPaR parallel manipulator based on Arduino Uno is a robot whose arms have prismatic (translation) and rotary (rotation) joints that move together. The actuator on the 3-RRPaR parallel manipulator is placed on the base so that only the base joints move actively. This tool uses a stepper motor as its driving source. where the mechanics will move according to the file sent via the Arduino Uno microcontroller to the L293D motor driver and stepper motor. In order to become a 3-RRPaR parallel manipulator robot, a 3-RRPaR Parallel Manipulator Structure Design and Analysis process is required, motion analysis and control system design of the 3-RRPaR parallel manipulator, performance analysis of the 3-RRPaR parallel manipulator and design of the 3-RRPaR parallel manipulator manufacturing system.

Parallel robots offer advantages for many robotics applications, such as rigidity, speed, low-mass motion, and superior accuracy. However, the main drawback of parallel robots is their small workspace and limited manipulation capabilities within a specific area of that space.

Several research initiatives undertaken in this domain, particularly those by Clavel, have resulted in innovative architectures such as the renowned DELTA robot.

DELTA robots have attracted considerable attention in both academia and industry. The literature contains a wealth of information on the history and types of parallel robots. In general, a DELTA robot consists of an equilateral triangular base, with one arm (driven via a revolute joint) extending from each side. A small triangular plate is connected to each arm by a pair of parallelogram-shaped forearms. This results in three translational degrees of freedom, with one additional rotational degree of freedom not coupled to the end-effector, resulting in a single motor mounted to the base and connected to the end effector by a telescopic arm with two universal joints [13].

The parallel delta industrial robot is a type of parallel connection robot. Due to its compact structure, large rigid load, and less connection error, it is one of the most widely used robots. In its mechanical structure, a fixed platform, three input links, and a moving platform are connected together by three links consisting of four parallel links. Since the upper link is parallel to the lower link in the four parallel links, the moving platform is always parallel to the fixed platform, which is secured by the three parallel links. This provides three degrees of freedom (3DOF) movement capability within a predetermined area, with the help of its unique mechanical structure. Due to the parallel architecture, there is no cumulative deviation in any axis [14].

The 3-RRPaR parallel manipulator based on Arduino Uno is a robot whose arms have prismatic (translation) and rotary (rotation) joints that move together. The actuator on the 3-RRPaR parallel manipulator is placed on the base so that only the base joints move actively. This tool uses a stepper motor as its driving source. where the mechanics will move

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Based on the description above, it is necessary to analyze the performance of the 3-RRPaR Parallel Manipulator Robot to move materials.

2. Method

This research is based on robotics research that begins with making an initial design in the form of a sketch of a parallel manipulator robot and continues with testing the control system. At this stage, the links and joints of the parallel manipulator robot are first defined. Then the frame parts are made. All frame parts are then assembled. If all frame parts have been assembled perfectly, then the design stage is complete and can be continued to the simulation stage using a control system with Arduino Uno software. In the simulation stage, all possible robot movements are simulated to obtain the workspace of the parallel manipulator robot. The next stage is to control the robot's movements from 3 active links and 3 passive links.

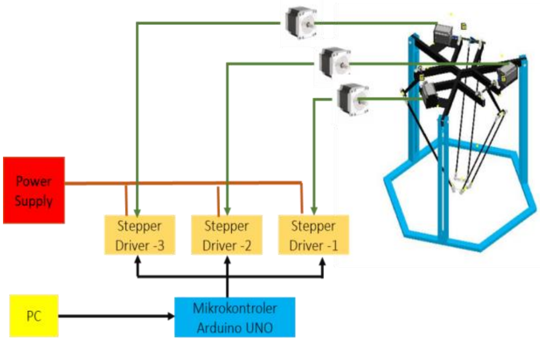


Figure 1. Control System Schematic of 3-RRPaR Parallel Manipulator Robot

Based on the 3-RRPaR Parallel control system scheme (Figure 1), the first thing to do is prepare the components that will be used for control after that prepare the stepper motor and servo motor that will be controlled for testing, then connect the motor cable to the driver to turn on the stepper motor, after connecting the motor cable to the driver where the black cable (a +) green (a-) red (b +) blue (b-) then install the PUL +, DIR +, AND ENA + cables connected to the GND of the Arduino while the PUL-, DIR-, and ENA - are connected to the Arduino pins 5, 6, 7 and the power supply is connected to GND and VCC is on the driver. For servo B, C, Z it is connected to 5v on the Arduino and for the black cable it is connected to GND and the yellow cable is connected to the input pin on the Arduino then control is carried out using the Arduino software.

3. Results and Discussion

In Figure 2 we can see the gripper test on the servo motor with the circuit below, we can see the position of the servo motor mode pin is on mode pin 11 using a black jumper cable (GND) and a red input cable (5V). This test is carried out so that the servo motor can work when trying to enter the robot program into the Arduino.

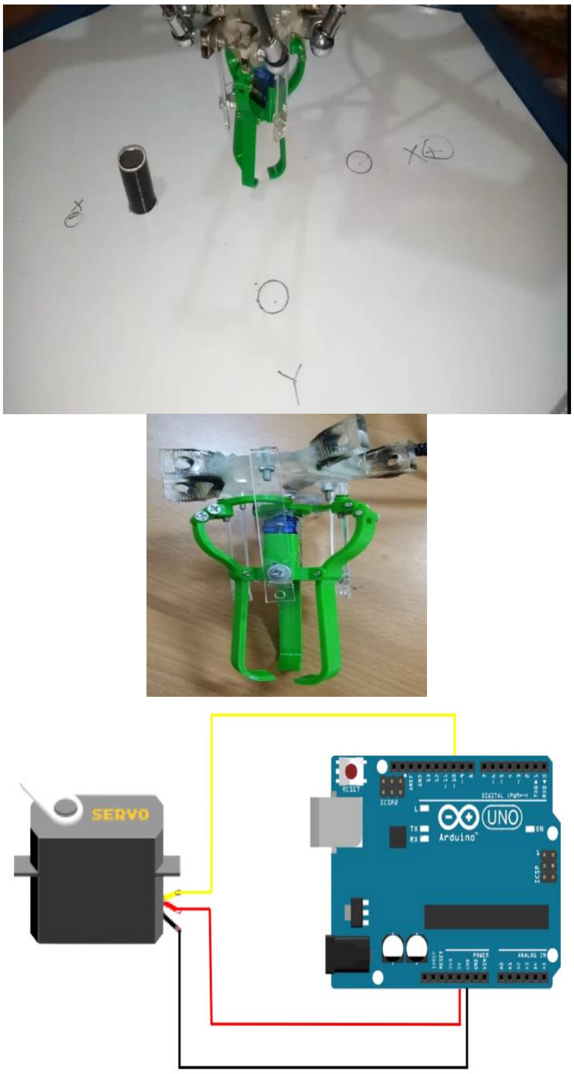


Figure 2. Gripper

The gripper motion control settings are set using a PC/laptop, the settings are made to facilitate data collection with the gripper control settings (Table 1).

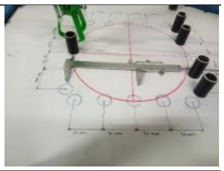
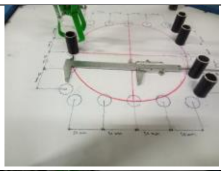
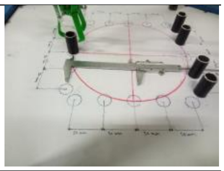
Table 1. Gripper control settings

No	Opened-diameter (puls)	Closed-Diameter (puls)
1	400	0
2	400	0
3	500	200

X-axis pick and place testing

This X-axis unidirectional test has three types of specimens, each specimen has a different weight, namely specimen one weighing 7.3 grams, specimen two 26.4 grams, specimen three 49.9 grams. The results of the X-axis pick and place robot test are in Table 2. In Table 2, it can be seen that the X-axis test with the first, second, and third specimens with a length of R 100 mm and an actual 98 mm has an error of 2 mm. So in this specimen test, we can conclude that the results obtained are inaccurate due to problems in the manufacturing design.

Table 2. Evaluation of pick and place along the X-axis

No	$R_{sim.}$ (mm)	$R_{act.}$ (mm)	Error (%)	t (s)	V (m/s)	Testing Results
1	250	248	0,2	10	25	
2	250	248	0,2	10	25	
3	250	248	0,2	10	25	
4	250	248	0,2	10	25	
5	250	248	0,2	10	25	

Y-axis pick and place testing

In this Y-axis unidirectional test, there are three types of specimens, each specimen has a different weight, namely specimen one weighing 7.3 grams, specimen two 26.4 grams, specimen three 49.9 grams. The results of the Y-axis robot pick and place test are in Table 3.

Table 3. Evaluation of pick and place along the Y-axis

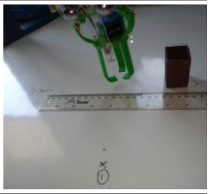
No	$R_{sim.}$ (mm)	$R_{act.}$ (mm)	Error (%)	t (s)	V (m/s)	Testing Results
1	200	198	0.2	10	20	
2	200	198	0.2	11	18.18	
3	200	198	0.2	12	16.67	

Table 3 shows that the Y-axis specimen testing with specimens one, two, and three with an R length of 100 mm and an actual length of 98 mm had an error of 2 mm. Therefore, in this test, we can conclude that the results obtained were inaccurate due to problems in the manufacturing design.

From the results of the pick and place gripper test above, it can be concluded that the results obtained after testing three specimens with different weights in the X-axis test and the Y-axis test with less accurate or imprecise results. In the X-axis test which was carried out five times with the same object weight and the same results, it turned out that in the fifth test the object fell or was not the same in the first, second, third and fourth tests. This was caused by an error in the control settings or the coordinate points were not correct and the Y-axis test was carried out with three specimens with different weights and the results obtained were the same, namely 98 mm with an error of 2 mm.

After testing along the X-axis and Y-axis, the results were inaccurate and resulted in a 2 mm error. This was due to the following:

a) Clutch slippage causes the active link shaft to wear.
b) The clutch is not fixed/dead.
c) The upper frame is not perpendicular to the lower frame.
d) The passive links are not the same length.

4. Conclusion

Based on the results of the 3-RRPaR Parallel Manipulator Robot test, it can be concluded that the X and Y axes were set at R 100 mm, while the actual value was 98 mm, with an error of 2 mm. This test was conducted with three specimens of varying weights.

In the X-axis test, five tests were conducted with the same specimen weight, and an error of 2 mm was observed. In the fifth test, the object fell due to incorrect control settings or incorrect coordinates.

After conducting the overall test, the results were found to be inaccurate and contained an error of 2 mm. This was due to the robot's imprecise performance, the upper frame manufacturing process not being aligned with the lower frame, the passive links being of different lengths, and the couplings being inconsistent.

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